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A Footprint Family extended MRIO model to support Europe's transition to a One Planet Economy

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HIGHLIGHTS

► The paper describes, from a theoretical point of view, a suite of indicators named "Footprint Family".
► It provides a technical description of the MRIO model created to operationalize the Footprint Family concept.
► It discusses on how policy-makers and civil society can best use the model's outcomes.
► It lists pros and cons of the model and gives indications on how to improve it to track a wider range of human impacts.

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ABSTRACT

Currently, the European economy is using nearly three times the ecological assets that are locally available. This situation cannot be sustained indefinitely. Tools are needed that can help reverse the unsustainable trend. In 2010, an EC funded One Planet Economy Network: Europe (OPEN:EU) project was launched to develop the evidence and innovative practical tools that will allow policy-makers and civil society to identify policy interventions to transform Europe into a *One Planet Economy*, by 2050.

Building on the premise that no indicator alone is able to comprehensively monitor (progress towards) sustainability, the project has drawn on the Ecological, Carbon and Water Footprints to define a *Footprint Family* suite of indicators, to track human pressure on the planet. An environmentally-extended multi-regional input–output (MRIO) model has then been developed to group the Footprint Family under a common framework and combine the indicators in the family with national economic accounts and trade statistics.

Although unable to monitor the full spectrum of human pressures, once grouped within the MRIO model, the Footprint Family is able to assess the appropriation of ecological assets, GHG emissions as well as freshwater consumption and pollution associated with consumption of specific products and services within a specified country. Using MRIO models within the context of Footprint analyses also enables the Footprint Family to take into account full production chains with technologies specific to country of origin.

1. Introduction

Over the last half century, nations throughout the world have changed dramatically; most have undergone significant economic growth, better welfare provisions and reductions in poverty (UNDP, 2006; UNEP, 2007). Despite some of the obvious benefits of such change, there have been negative consequences upon natural ecosystems, the biosphere and the many species that inhabit it (Butchart et al., 2010; Ellis et al., 2010; Lenzen et al., 2012a). The future ability of our natural capital to provide for humanity is being degraded as the demands upon natural systems rapidly increase due to the swelling global economy and the need to attain better standards of living (Goudie, 1981; Haberl, 2006; Nelson et al., 2006; Rockström et al., 2009). Barnosky et al. (2012) have argued that a planetary-scale critical transition is approaching as a result of the many human pressures, and that tools are needed to detect early warning signs and forecast the consequences of such pressures on ecosystems.As one of the world's largest economies, Europe has been characterized by trends of growth in the last decades so that Europe overall demand on the biological capacities of the planet has risen by more than 70% since 1961 (WWF, 2012).

The accumulation of human pressure is fundamental to many environmental issues and world leaders face the challenge of selecting appropriate policies and investments to prevent further detrimental effects (Bauler, 2012; Heink and Kowarik, 2010; Moldan et al., 2012). A broad range of empirical measurements exists that can be used to identify the driving forces behind impacts and select policies

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to reduce them while maintaining economic and societal well-being (e.g., Chapin et al., 2009). However, selected indicators have been often oversimplified in order to better communicate a particular issue and therefore lose the impact of other factors that should also be considered. A classic example is the use of Gross Domestic Product (GDP) as a measure of economic performance in a nation, but this does not include any consideration of societal well-being. The European Union has been assessing different indicators that are better related to societal goals, including reducing environmental impacts and providing better quality of life in conjunction with economic indicators; this is part of its "Beyond GDP" process (EC, 2009).

The aim of this paper is to describe the tools developed in a recently concluded FP7 project named "One Planet Economy Network Europe (OPEN:EU)" (www.oneplaneteconomynetwork.org), and the way these tools can support policy and decision making activities at EU level.

Under this project, three indicators have been identified as useful to assess environmental issues – Ecological, Carbon and Water Footprints (EF, CF and WF) – and grouped together to form a suite of indicators called Footprint Family (Galli et al., 2012). First introduced from a conceptual viewpoint, the Footprint Family has been then further developed within the OPEN:EU project and coupled with an environmentally-extended multi-regional input–output (MRIO) model (Ewing et al., 2012; Weinzettel et al., 2011). This model was developed to better understand the relationships between producing and consuming sectors of multiple countries across the globe and thus allow policy-makers and civil society to identify policy interventions to transform Europe into a One Planet Economy (i.e., an economy that respects all environmental limits and is socially and financially sustainable, enabling people and nature to thrive) by 2050.

2. Methods: Footprint indicators

The term 'Footprint' is a well-known expression, commonly associated with anthropogenic pressures upon the Earth. Each Footprint indicates a particular class of pressures associated with the activities of an individual or group assessed from the life-cycle perspective:

- Potential for global warming due to the release of GHGs is indicated by the Carbon Footprint (Hertwich and Peters, 2009),
- Water consumption and pollution is indicated by the Water Footprint (Hoekstra, 2003),
- Overconsumption of the regenerative capacity of the Earth's biosphere is indicated by the Ecological Footprint (Wackernagel et al., 2002).

2.1. Ecological Footprint

The Ecological Footprint is a resource and emission[1] accounting tool designed to track human demand on the biosphere's regenerative capacity. Resource production and carbon dioxide sequestration are tracked from human demands, both directly and indirectly; this can then be compared with the Earth's ecological assets known as "biocapacity" (Borucke et al., 2013; Kitzes et al., 2008; Wackernagel et al., 2002). The Ecological Footprint is able to inform about, in an integrated sense, the ecological consequences of the demands humans place upon the biosphere and its natural systems.

2.2. Carbon Footprint

The Carbon Footprint measures the total amount of greenhouse gas (GHG) emissions that are directly and indirectly caused by an activity or are accumulated over the life cycle stages of a product, good or service. This is inclusive of activities of individuals, populations, governments, companies, organizations, processes, industry sectors, etc. For all cases, all direct (on-site, internal) and indirect emissions (off-site, external, embodied, upstream, and downstream) are taken into account. The amounts of GHGs are weighted according to their global warming potentials. More specific aspects, such as which GHGs are included and how double-counting is addressed, can vary (Wiedmann and Minx, 2008).

2.3. Water Footprint

The Water Footprint accounts for the appropriation of natural capital in terms of the freshwater volumes required for human consumption (Hoekstra et al., 2009) and was introduced as a response to the need for a consumption-based indicator of water use (Hoekstra, 2003). There is a close link between the virtual water concept (Allan, 1998) and the Water Footprint, as this latter represents the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by business.

3. The Footprint Family: a theoretical definition

The Footprint Family was developed during the OPEN:EU project to bring together the Ecological, Carbon and Water Footprint. It is defined as a suite of accounting tools characterized by a consumption-based perspective able to track human pressure on the surrounding environment. More precisely, pressure is here defined as appropriation of biological natural resources and CO_2 uptake, emission of GHGs, and consumption and pollution of global freshwater resources (Galli et al., 2012).

Separately the three Footprints focus on distinct aspects of sustainability and answer different research questions; in this respect, individually they are relatively limited in their capacity to fully encompass the complexity of sustainable development. By creating the Footprint Family, it is possible to illustrate a more holistic and multidisciplinary approach. By looking at the amount of bioproductive area people demand because of resource consumption and waste emission, the Ecological Footprint can be used to inform on the impact placed on the biosphere and its ecological assets. By quantifying the effect of resource use on climate, the Carbon Footprint can be used to inform on the impact humanity places on the atmosphere. Lastly, by tracking real and hidden water flows, the Water Footprint can be used to inform on the impact humans place on the hydrosphere. These three indicators can therefore be regarded as complementary in the sustainability debate.

The Footprint Family is intended to assist policy makers in better understanding the pressures that humanity places upon the planet and its life supporting networks; it allows for a multidisciplinary sustainability assessment and a more comprehensive monitoring of the environmental pillar of sustainability. However, key sustainability-related topics such as human health, social development and well-being cannot be monitored using the Footprint Family. Moreover, relevant environmental issues such as the consumption of abiotic resources, use of nuclear energy and the release of toxic materials cannot be addressed via the Footprint Family as currently defined.

4. The Footprint Family extended multi-regional input–output (FF-MRIO) model

Input–output analysis was first proposed by Leontief (1936) as an economic modeling technique for understanding financial transactions between economic sectors, producers and consumers, within a country. The use of input–output analysis to support physical flow accounting gained early acceptance in the '70s but it was only in the '80 that the mathematical model for environmental extensions to input–

[1] CO_2 is the only greenhouse gas accounted by the Ecological Footprint method.

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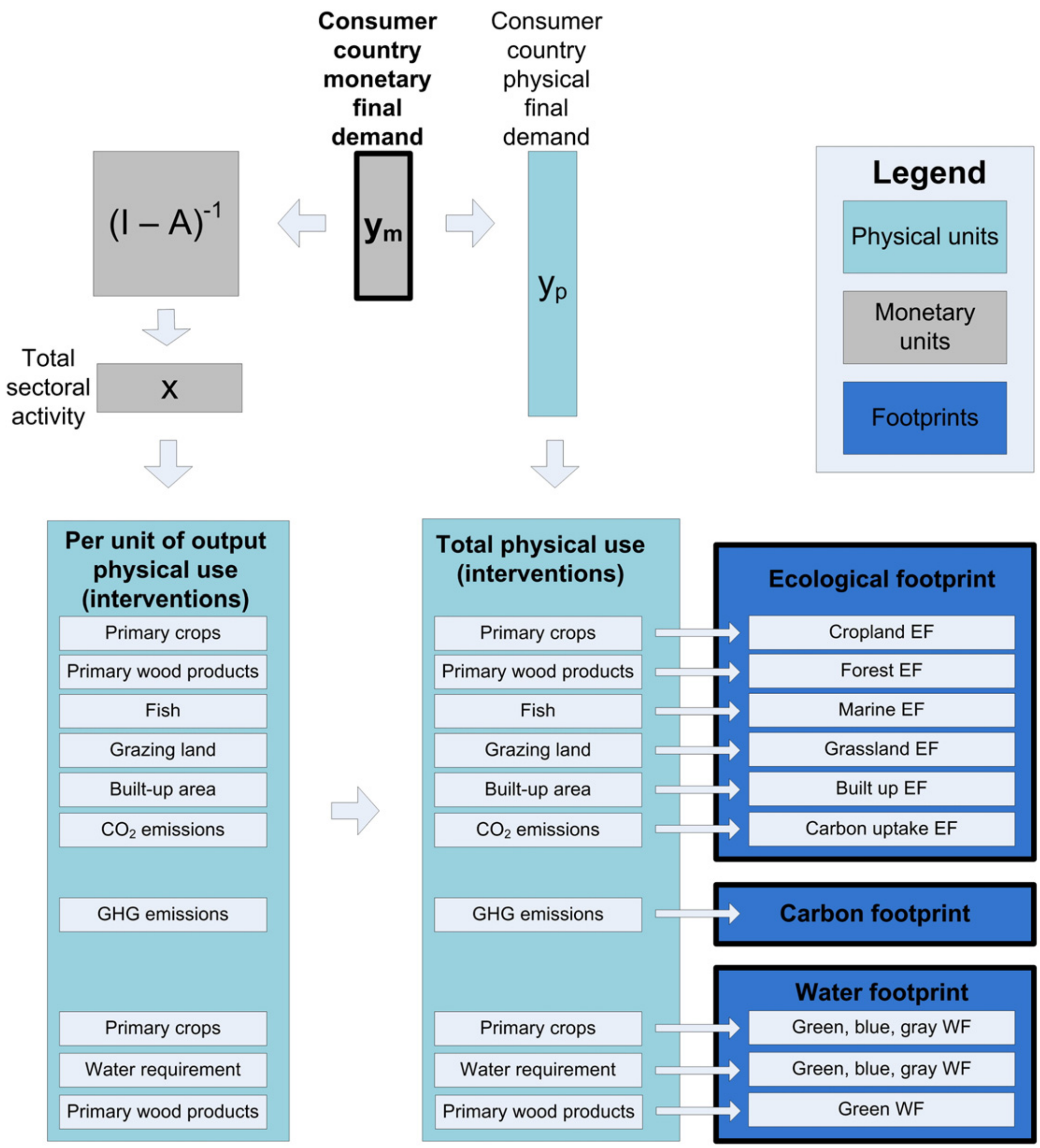

Fig. 1. Overview of the Footprint Family extended multi-regional input–output (FF-MRIO) model.

output tables was developed (Miller and Blair, 1985). Environmental extensions were added to the IO framework to track the environmental load (e.g. raw materials extracted, pollutants emitted, etc.) associated with final demand activities (Wiedmann, 2009). In the last three decades, environmentally extended input–output models have been utilized for material and energy flow accounting, land use accounting, to forecast trends and measure eco-efficiency and, recently, for Footprint analyses.

Traditionally, input–output (IO) or multi-regional input–output (MRIO) models have been used within the Carbon Footprint accounts (Druckman and Jackson, 2009; Hertwich and Peters, 2009; Minx et al., 2009; Peters, 2010; Peters et al., 2011; Wiedmann and Minx, 2008). Attempts have also been made at using IO or MRIO models in calculating Ecological and Water Footprints (Bicknell et al., 1998; Feng et al., 2011, 2012; Hubacek and Giljum, 2003; Hubacek et al., 2009; Lenzen and Murray, 2001; Turner et al., 2007; Wiedmann et al., 2006; Yu et al., 2010; Zhao et al., 2010); however, the majority of countries' Ecological and Water Footprint analyses have been performed through the use of process-based LCA data and physical quantities of traded goods (Global Footprint Network, 2011; Hoekstra and Chapagain, 2007; Hoekstra et al., 2009; Kitzes et al., 2008). As such, a single and shared input–output model has not been used in calculating Ecological, Carbon and Water Footprint and it was therefore necessary to bring the three indicators together under a streamlined ecological–economic modeling system within the definition of the Footprint Family (Weinzettel et al., 2011) to allow direct comparison of the indicators. An MRIO modeling framework was identified as the most suitable one to harmonize the Footprint Family. The MRIO model used within the OPEN:EU project is based on the GTAP 7 database, which distinguishes 57 industries within 113 regions covering the entire global economy (Narayanan and Walmsley, 2008).

Input–output (IO) models are well suited for the analysis of environmental impacts caused by human activities in complex economic systems. The direct link between economic activities and their subsequent impacts upon the environment can be highlighted by using environmentally-extended IO models, which involve evaluation of such impacts along complete supply chains for services and products. Utilizing a multi-regional framework significantly adds to the depth of the analysis, tracking international trade and its environmental repercussions (Wiedmann et al., 2007). It has been noted that the MRIO model is the only accounting framework of its kind that is able to successfully capture the intricate streams of supply and demand across the globe by following the complex systems of national and international financial transactions.

The environmentally-extended input–output framework enables investigating international supply chains and is ideally suited to identify the locations of environmental impact hot spots associated with consumption patterns (Peters and Hertwich, 2006; Wood and Lenzen, 2009).

Consumption-based MRIO accounting has already been used to support discussions in global climate policy about allocation of responsibility and priority setting for pressure reduction (Davis et al., 2011; Guan et al., 2008; Hertwich and Peters, 2009; Lenzen et al., 2007; Munksgaard et al., 2005; Peters, 2008; Peters and Hertwich, 2008; Peters et al., 2012; Tukker et al., 2006; Wiedmann, 2009). By developing a Footprint Family extended MRIO (FF-MRIO) model it is thus possible to perform inter-industry analyses of the linkages across multiple economies. However, a new method had to be developed for the integration of Ecological and Water Footprints into the MRIO framework. Such a method has been developed within the OPEN:EU project and it is described by Ewing et al. (2012).

A high level of detail in commodity classification was maintained while integrating the current accounts for Ecological and Water Footprints (traditionally calculated at the product level) within the more complete (in terms of multi-regional analysis), but less detailed (in terms of sectoral aggregation) MRIO framework. For instance, Ecological and Water Footprint analyses use FAO data in calculating the Footprint embedded in agricultural products. The high level of resolution of FAO data allows calculating the Footprint of nearly 170 crop products. Conversely, GTAP 7 distinguishes 57 industry sectors, of which only about 13 are related to agricultural activities. The grouping of the many agricultural products into few economic sectors and the consequent loss of resolution have so far prevented Ecological and Water Footprint practitioners to fully adopt IO or MRIO model in their analyses.

The FF-MRIO model introduced by Ewing et al. (2012) addresses this issue as it comprises a hybrid methodology which constitutes the top-down economic modeling inherent within the classic MRIO and the bottom-up physical resource accounting typical of the Ecological and Water Footprint frameworks. Direct Footprint requirements are calculated with a process-based approach and indirect Footprint demands via a monetary model (Ewing et al., 2012; Weinzettel et al., 2011).

Previous attempts at creating hybrids models to harmonize physical unit data of product use and standard economic/environmental accounting have been made in the field of Industrial Ecology (e.g., de Haes et al., 2004; Heijungs and Suh, 2002; Hubacek and Sun, 2001; Lenzen, 2002; Lenzen et al., 2004; Suh, 2004; Suh et al., 2004; Weinzettel and Kovanda, 2009); however, this is the first time such a harmonization has been performed for Ecological, Water and Carbon Footprint indicators, within the same model. The general structure of the FF-MRIO model, alongside with a distinction among raw data, physical and monetary values used in the model, is presented in Fig. 1 (see Ewing et al., 2012 and Weinzettel et al., 2011 for a detailed description of the model). Results from the application of the FF-MRIO model at EU-27 level can be found in Steen-Olsen et al. (forthcoming).

5. FF-MRIO merits, drawbacks and potential improvements

This integration process is not without its drawbacks. There is some loss in resolution of data since the input–output tables require sectoral-level assessments rather than the detailed product-level provided by Footprint indicators and there is also a reduction in temporal coverage as MRIO models are only available for particular years. However, through the addition of a satellite account, the product detail within the Ecological and Water Footprints accounts is maintained and complemented by the monetary MRIO model (Ewing et al., 2012). By incorporating a large amount of additional detail related to primary products, such as crops and forestry products, and by tracking these products in physical units, the FF-MRIO model developed in the OPEN:EU project enables calculation of direct footprints at the individual product level. Thus using the MRIO can identify the feedback effects where production changes in a region are caused by intermediate demand changes in an alternative region. As such, insight into the environmental trade-offs driven by different inter-industry interdependencies and trade are provided by the multilateral trade flows within the MRIO model (Weinzettel et al., 2011).

The FF-MRIO model harmonizes the Ecological, Water and Carbon Footprint calculations. Where the Ecological and Water Footprints are commonly linked in terms of the use of physical unit production data in their calculations, using this model enables them to be linked with the calculation of national Carbon Footprints; this creates the opportunity, for the first time, for direct comparisons between each of the three Footprints in the Footprint Family, for all of the EU-27 countries.

Along the line of the more standardized and widely applied indicators used here (Ecological, Water and Carbon Footprints), other footprint-type of indicators have been recently introduced such as the land footprint[2] (Weinzettel et al., submitted for publication; Lugschitz et al., 2011), the nuclear footprint (Stoeglehner et al., 2005; Wada, 2010), the product environmental footprint (Manfredi et al., 2012), the material footprint (Schoer et al., 2012) and the nitrogen footprint (Leach et al., 2012). Alongside with these "environmental footprints", a recent review study conducted by Čuček et al. (2012) has highlighted the existence of footprint-type of indicators intended to monitor the social and economic dimensions of sustainability. Although a clear definition of these indicators is still missing, according to Čuček et al. (2012), social footprint indicators account for the impacts on anthropogenic capital (human, social, and constructed), while economic footprint indicators track the total direct and indirect economic impacts (e.g., income distribution, employment, and tax revenue) of specific processes, products, or activities, a region or a country. In the future, the Footprint Family suite of indicators and the FF-MRIO model as described in this paper could be expanded to include the above mentioned indicators and arrive at a suite capable of assessing a wider spectrum (embracing the three pillars of sustainability) of human pressures.

Moreover, the FF-MRIO model created in the OPEN:EU project could also be improved through the use of updated and/or more detailed (in terms of sectoral breakdown and geographical coverage) MRIO models such as, for instance, the EXIOPOL (Tukker et al., 2009) or EORA (Lenzen et al., 2012b) MRIO databases. A detailed comparison of the GTAP 7 and EXIOPOL models is available in Hertwich and Peters (2010); the EORA model was not included in such comparison study as it was not ready at the time of the study.

6. Conclusions

Among the aims of the OPEN:EU project was to identify a suite of indicators, the Footprint Family, enabling policy and decision makers to more comprehensively track the current resource use and pressures this use generates on various life-supporting compartments of the Earth (biosphere, atmosphere and hydrosphere).

Using an MRIO model, the three indicators within the Footprint Family were brought together in a streamlined economic and ecological framework. Development of a Footprint Family extended MRIO (FF-MRIO) model improved the allocation of footprints to the complex mix of products consumed by humanity, through the itemization of the indirect impacts associated with international supply chains. Policy makers can more readily understand the environmental

[2] Although the term "land footprint" began to be used only recently, studies incorporating land use analyses and input–output modeling can be found in the literature since the late '90s (Bicknell et al., 1998; Costello et al., 2011; Eder and Narodoslawsky, 1999; Erb, 2004; Ferng, 2001; Hubacek and Giljum, 2003; Hubacek and Sun, 2001).

consequences of economic activities by assessing the combination of the Ecological, Water and Carbon Footprint.

Based upon the methodological framework introduced here, the EUREAPA online tool (see https://www.eureapa.net/) has been created through the OPEN EU project, which enables the evaluation of policy scenarios on a national and international level (Roelich et al., 2011). We believe this tool can help policy-makers and civil society to identify the most adequate policy interventions to transform Europe into an economy that respects all environmental limits and is socially and financially sustainable, enabling people and nature to thrive (a One Planet Economy).

The model has been designed in such a way that it can be easily extended to incorporate bespoke research, novel footprint indicators or datasets (e.g. new and more updated MRIO models), as required by policy-makers in the future.

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